IMPROVING SENSOR MODEL ACCURAY USING MULTI-BAND AND MULTI-PATCH BASED MATCHING

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ABSTRACT: The accuracy of precise geometric correction of satellite images depends on the quality of Ground Control Point (GCP) data. To obtain high geometric correction accuracy with a limited number of GCP chips, we propose a method to acquire high quality GCP data using multi-band and multi-patch based matching. The proposed matching method works as follows. Firstly, we define initial search range in a satellite image using the initial sensor model. To define search range more precisely, we produce image pyramid of three reduced scale layers for the image and GCP chip. In this image pyramid, we performed single-band and single-patch matching between GCP chip and each image of the image pyramid. Secondly, we divide a multi-band GCP chip into six patches per each band: one patch with the original GCP chip size, one 2/3 size patch centered on the chip center and four 2/3 size patches at upper left, upper right, bottom left and bottom right of GCP chip. Finally, we adjusted search range of each patch precisely using the matching result of the image pyramid and performed multi-band and multi-patch matching. Through this matching process, we obtain 18 matching points per GCP chip. To verify the proposed method, we carried out experiments using KOMPSAT-3 and KOMPSAT-3A Level 1R pan-sharpened RGB 3-band images and GCP chips made from 0.25m Ground Sample Distance (GSD) aerial orthogonal images. We compared the proposed method with single-band and single-patch based matching. As a result of the experiment, the proposed method showed the best performance. When using this method, we could obtain the most inliers of matching points and the best accuracy of the sensor model.

1. INTRODUCTION

Over the past 40 years, the spatial resolution of satellite imagery has improved approximately 250 times, from 80 m in Landsat Multi-Spectral Scanner(MSS) to 0.31 m in WorldView3 (Kang and Lim, 2015). High-resolution satellite imagery is used for precision change detection and topographic information extraction, as well as for the production of various themes and geographic information systems (Lee et al., 2017). Accordingly, Korea government established a plan to provide high-resolution satellite images through Korea Multi-Purpose Satellite (KOMPSAT) and Compact Advanced Satellite (CAS) series (Kang and Lim, 2015; Hwang et al.,2016).

As the demand and supply of high-resolution satellite images are increasing, automatic geometry correction technology is required to maintain high geometric accuracy of such images. To acquire this goal, automatic precision sensor modeling must be involved. Since precision sensor model relies on Ground Control Point (GCP) data, it is important to extract sufficient number of high quality GCP data automatically. Automatic GCP extraction is generally performed by matching between satellite images and GCP chips. However, it is very difficult to construct sufficient GCP chips for high resolution satellite images. In order to manufacture GCP chips for high-resolution satellite images, it is necessary to secure high-accuracy ground coordinates and high-resolution orthoimage data, and even after securing all the data, it is also necessary to clearly identify the position of the ground coordinates in the orthoimage (Yoon et al., 2018).

In the previous research, we analyzed and validated the feasibility of establishing a precise sensor model for high-resolution satellite imagery using unified control points (Yoon et al., 2018). However, the number of currently established unified control points is limited and may not be enough to cover the entire South Korean territory. Therefore, it is necessary to study how to obtain a sufficient number of high-quality GCP data using a limited number of GCP chips. In this paper, we propose a method to get high quality GCP data using multi-band and multi-patch based matching.

2. METHODOLOGY

In this paper, to improve sensor model accuracy, we studied a method to obtain a sufficient number of high-quality GCP data. We divided a GCP chip into 6 patches and 3 band, which did not degrade matching success rate compared to original GCP chip matching. The overview of the proposed method is below.

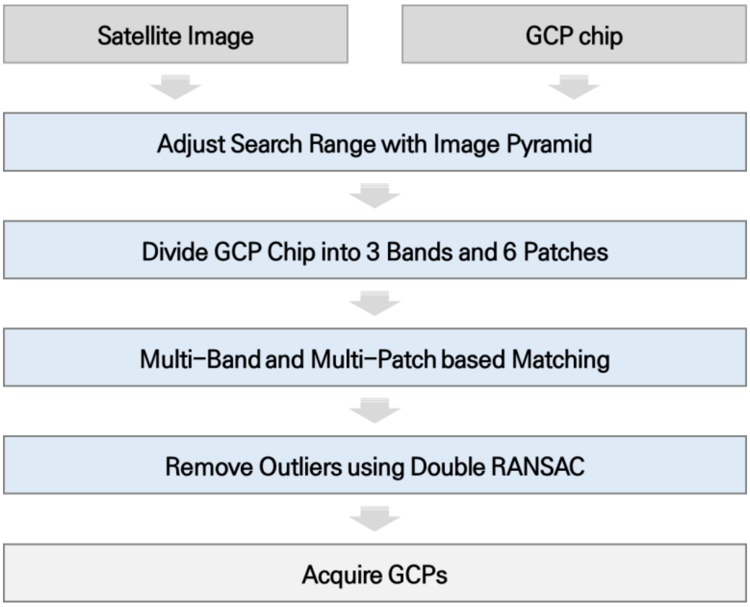


Figure 1. Overview of the proposed method

2.1 Adjust Search Range with Pyramid Image

In our proposed method, we performed multiple matching using single-band GCP chip patches. These patches have less image information than original GCP Chip. Therefore, to improve matching success rate, search range should be set precisely.

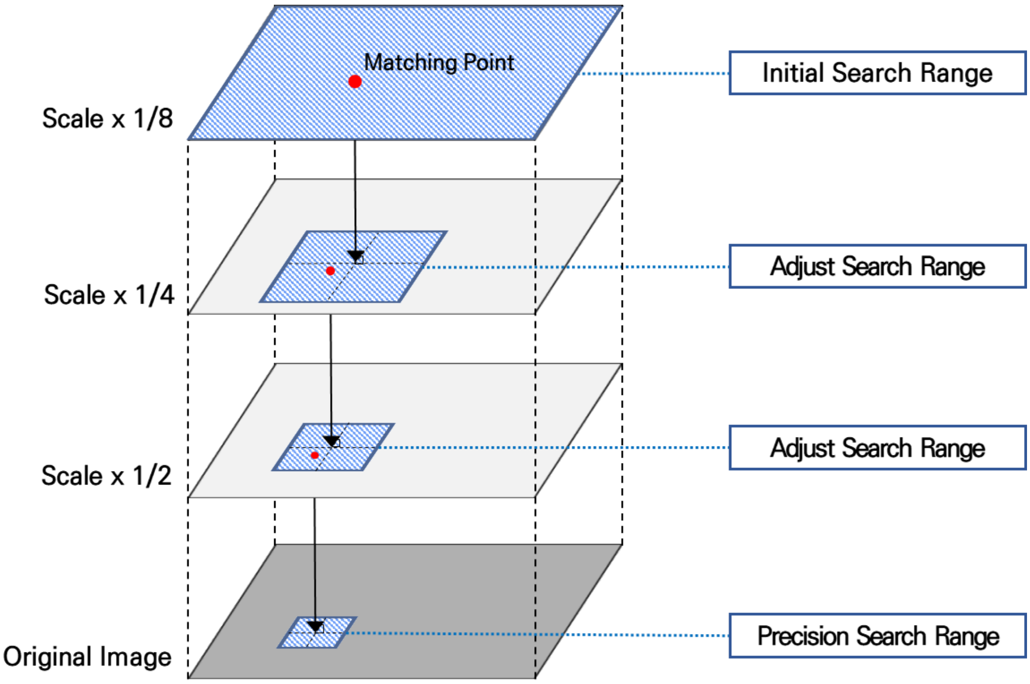


Figure 2. Overview of the proposed method

Firstly, using initial sensor model, we defined initial search range. However, this initial search range was not set precisely, because the initial sensor model has geometric error. So, as shown in Figure 2, we produced the pyramid image of three layers from 8 times reduced scale to 2 times reduced scale for the satellite image and GCP chips. In each layer, we conducted single-band and single-patch matching and adjusted search range to half-size centered on the matching point. The single-band and single-patch matching was conducted by Zero Mean Normalized Cross Correlation(ZNCC) matching algorithm, because in the previous study, ZNCC algorithm show the best performance in the reduced scale layers (Yoon, 2019).

$$\mathrm{ZNCC(c,r)} = \frac{\sum_{j=1}\sum_{i=1}[I_t(c+i,r+j)-\mu(I_t)]\times[I_r(i,j)-\mu(I_r)]}{\sqrt{\sum_{j=1}\sum_{i=1}[I_t(c+i,r+j)-\mu(I_t)]^2}\sqrt{\sum_{j=1}\sum_{i=1}[I_r(i,j)-\mu(I_r)]^2}} \qquad (1)$$

In case of KOMPSAT-3 and KOMPSAT-3A, which are high-resolution satellites, the initial sensor model accuracy is about 30m and 20m, respectively (Jeong et al., 2014; Yoon and Kim, 2018). Therefore, we set the initial search range size as 200 x 200 pixels considering initial sensor model accuracy and deviation. After adjusting search range, final precision search range had 25 x 25 pixel size.

2.2 Multi-Patch Based Matching

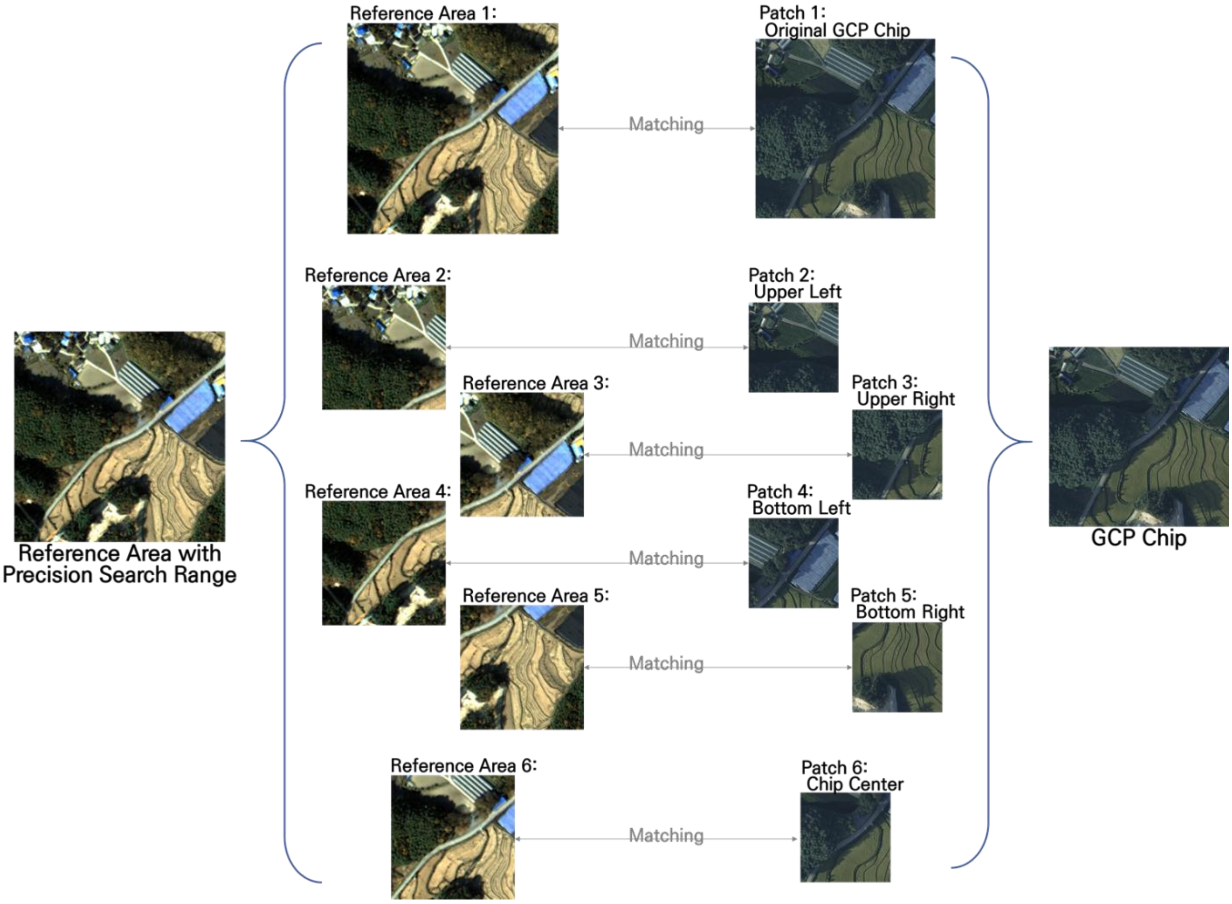


Figure 3. Example of multi-patch GCP chip matching.

As imaging geometry of GCP chip does not correspond with that of satellite image, we should adapt the imaging geometry of each patch to that of the satellite image using initial sensor model, before matching. Since initial sensor model has geometric error, many outliers were occurred in this step (Son et al., 2019). Therefore, we divided a GCP chip into 6 patches; one patch with the original GCP chip size, one 2/3 size patch centered on the chip center and four 2/3 size patches at upper left, upper right, bottom left and bottom right of GCP chip. As each GCP chip patch has only a partial region of the original GCP chip, the patch that has the region of small imaging geometry adaption error were able to obtain more precision GCP than original GCP chip.

According to previous research, we performed matching each patch and image using Census matching algorithm, which show the best performance in high-resolution satellite image (Yoon, 2019).

2.3 Multi-Band Based Matching

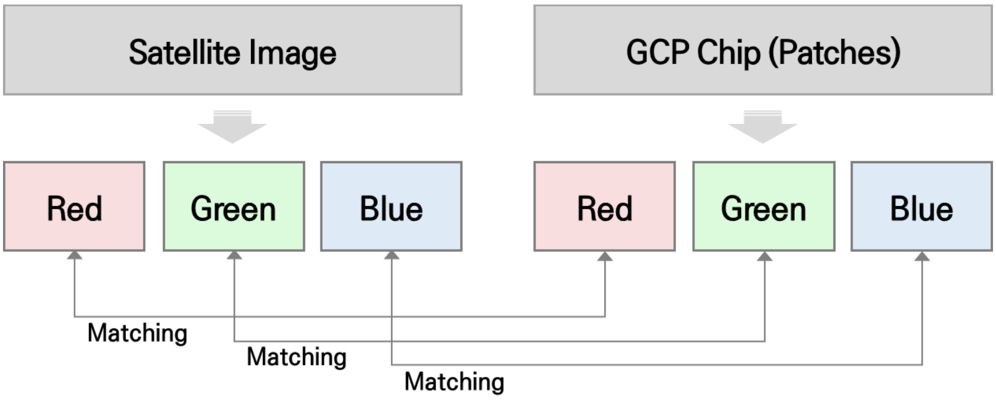


Figure 4. multi-band GCP chip matching

Since satellite imagery photograph a wide area at various times, the band that is most advantageous for GCP chip matching can be changed depending on the situation. Therefore, we divided each GCP chip patch and satellite image into 3 band and performed matching 3 times.

2.4 Double RANSAC

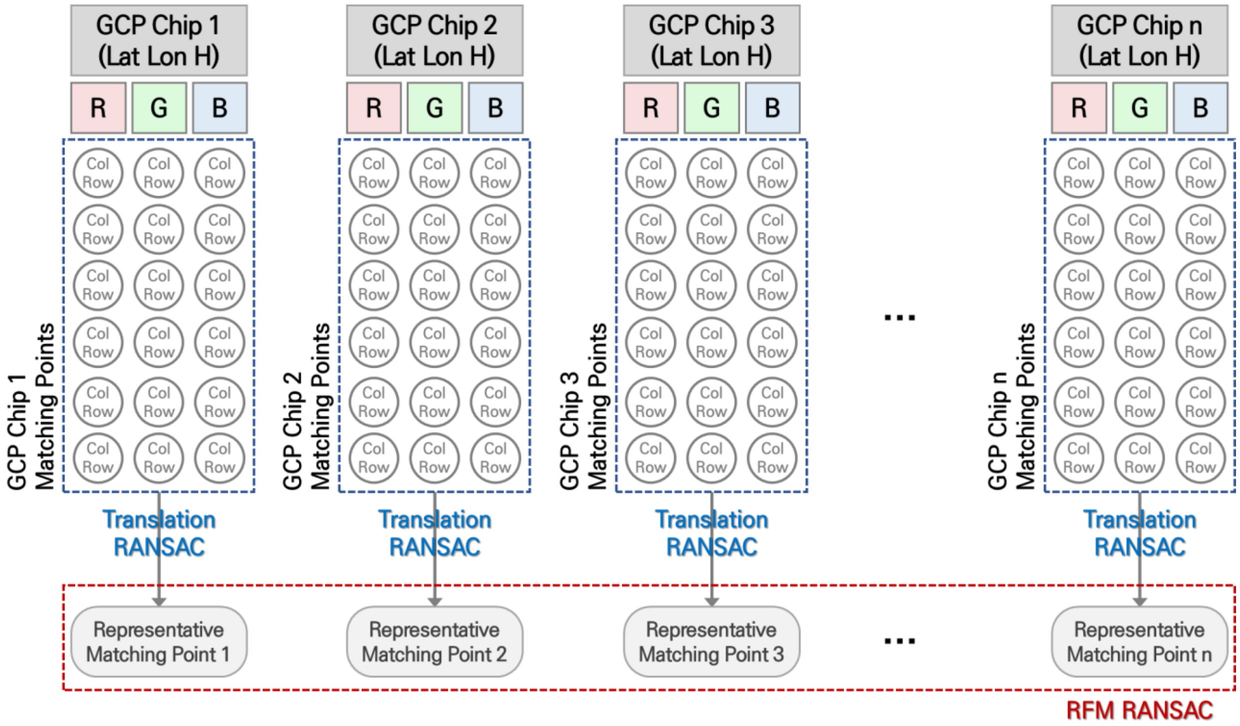


Figure 5. Double RANSAC

As a result of multi-patch and multi-band based matching, we were able to obtain 18 times more matching points than single-patch and singe-band based matching. To improve sensor model accuracy using these results, the step of removing outliers is the most important.

As shown in Figure 5, we removed outliers by conducting double Random Sample Consensus (RANSAC). Since each 18 matching points of one GCP chip corresponds to the same ground coordinates, they should be the same ideal point, if all matching result was perfectly performed. Therefore, we conducted the first RANSAC in the matching point group of each GCP chip. In this group, we selected 1 sampling point and counted the number of supporting points within 2-pixels from the sampling point. The matching point with the largest number of supporting points is selected as the representative point, and the points outside 2-pixels from the representative point are determined by the outlier. Using the representative points, we performed the second RANSAC based on Rational Function Model (RFM). After the second RANSAC, if the representative value of a GCP chip group determined as inlier, we used all the group matching points that had determined as inlier at the first RANSAC as GCP. If the representative value of a GCP chip group determined as an outlier, we re-examined all matching points of the group using the best model of the second RANSAC and set inliers as GCP.

3. EXPERIMENTS

To validate proposed method, we compared this method with single-band and single-patch based matching. As shown in Table 1, Figure 6 and 7, we used KOMPSAT-3 and KOMPSAT-3A Level 1R pan-sharpened RGB 3-band images and GCP chips made from 0.25m Ground Sample Distance (GSD) aerial orthogonal images. For analyzing matching success rate, we conducted manual GCP chip matching and assumed this result as true matching point.

Table 1. Experiment data

	Scene-1	Scene-2	Scene-3	Scene-4	Scene-5	Scene-6
Satellite	KOMPSAT-3A		KOMPSAT-3			
Product Level	Level 1R					
Spectral Band	Pan-sharpened RGB 3-band Panchromatic: 450-900 nm Multi-Spectral 1 (Blue): 450-520 nm Multi-Spectral 2 (Green): 520-600 nm Multi-Spectral 3 (Red): 630-690 nm					
Orbit Number	06517	03283	29194	29194	28405	15289
Acquisition date	2016.05.30	2015.10.29	2017.11.06	2017.11.06	2017.09.13	2015.03.30
Scene Center (Lat./Long.)	36.28715327 /127.59039321	37.52602640 /127.89004906	36.80337308 /126.62052871	36.66831731 /126.65475428	35.34275796 /127.02420021	37.335097178 /127.928033281
No. of GCP chips	11	17	14	21	18	21


(a) (b) (c) (d)

Figure 6. Satellite Image used in experiment, (a) Scene-1, (b) Scene-2, (c) Scene-3, (d) Scene-4

Figure 7. GCP chip used in experiment

3.1 Matching Success rate according to Search Range

Table 2. Matching success rate according to search range

Scene Num.	No. of GCP Chips	No. of Matching Points	With Initial Search Range			With Precision Search Range		
			No. of Inliers	No. of Outlier	matching success rate	No. of Inlier	No. of Outlier	matching success rate
1	11	198	142	56	71.72 %	156	42	78.79 %
2	17	306	204	102	66.67 %	231	75	75.49 %
3	14	252	178	74	70.63 %	185	67	73.41 %
4	21	378	224	154	59.26 %	238	140	62.96 %
5	18	324	161	163	49.69 %	203	121	62.65 %
6	24	432	193	239	44.68 %	253	179	58.56 %
Total	**105**	**1890**	**1102**	**788**	**58.31%**	**1266**	**624**	**66.98 %**

We conducted an experiment to analyze the effect of precision search range using pyramid image. We performed multi-patch and multi-band based matching using the initial and precision search range. We analyzed error of each matching result using true matching point. If the matching error is more than 3 pixels, it is determined as outlier. As shown in Table 2, the matching success rate is improved in all scenes when matching is performed using the precision search range.

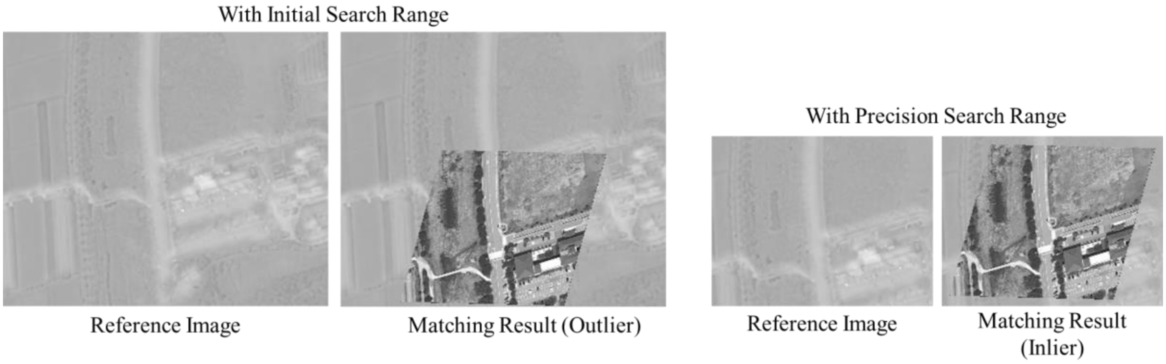


Figure 8. Example of matching results according to Search range

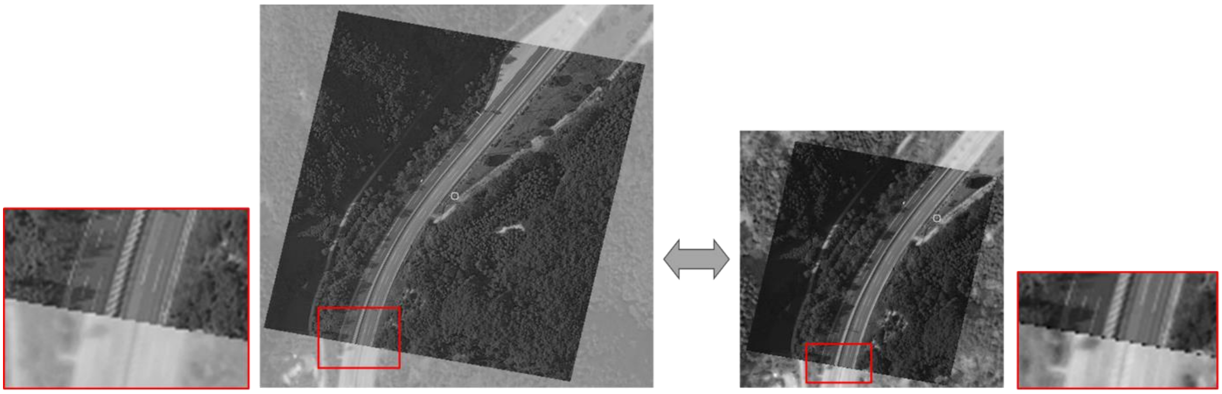
3.2 Acquired GCP Accuracy

Table 3. Accuracy of GCP

Scene Num.	No. of GCP Chips	Single-patch and Single-Band			Multi-patch and Multi-Band		
		No. of Matching Points	No. of Acquired GCPs	Average GCP Accuracy (pixel)	No. of Matching Points	No. of Acquired GCPs	Average GCP Accuracy (pixel)
1	11	11	10	1.15	198	140	1.10
2	17	17	15	2.58	306	134	2.07
3	14	14	12	1.91	252	131	1.82
4	21	21	16	1.35	378	140	1.45
5	18	18	11	2.84	324	80	2.57
6	24	24	13	1.99	432	209	1.51
Total	**105**	**105**	**77**	**1.97**	**1890**	**834**	**1.81**

To validate quality of GCPs that acquired from the proposed method, we conducted multi-patch and multi-Band based matching and then removed outlier using the double RANSAC. We also conducted Single-patch and Single-Band based matching using green band and then removed outlier using single RANSAC based on RFM. Each GCP Accuracy was calculated from the error of GCP image coordinates based on the true matching point.

As shown in Table 3, the multi-path and multi-band matching showed a better average GCP accuracy as well as the number of GCP than single-patch and single-band matching. Because we were able to obtain more precise matching points than single GCP chip matching as we used multi-patch and multi-band matching. Matching with the reduced-size patch was often more accurate than the Matching with original GCP Chip due to Imaging geometry adaption error (Figure 9).



High Imaging Geometry Adaption Error

Original GCP Chip Matching (7.30 pixels Accuracy)

Patch Matching (2.02 pixels Accuracy)

Low Imaging Geometry Adaption Error

Figure 9. Comparison original GCP chip matching and patch matching

3.3 Sensor Model Accuracy

Table 4. Accuracy of sensor model

Scene Num.	**No. of GCP Chips**	**Single-patch and Single-Band**			**Multi-patch and Multi-Band**		
		No. of Acquired GCPs	Modeling Point Accuracy	Check Point Accuracy (pixel)	No. of Acquired GCPs	Modeling Point Accuracy	Check Point Accuracy (pixel)
1	11	10	1.15	1.21	140	1.42	1.14
2	17	15	1.96	2.90	134	1.54	2.13
3	14	12	1.76	4.78	131	1.97	2.75
4	21	16	1.49	2.15	140	1.7	2.10
5	18	11	1.71	6.21	80	2.25	2.65
6	24	13	1.78	3.05	209	1.54	2.35
Total	105	77	1.64	3.38	834	1.74	2.19

We performed precise sensor modeling using each GCP set obtained in the previous experiment and analyzed the results. Firstly, we calculated modeling point accuracy with the points used for the precision sensor modeling, and then calculate the check point accuracy using the true matching point. as a result, Table 4 show each sensor model accuracy. In case of modeling point accuracy, GCP that acquired from single-patch and single-band based matching showed better accuracy overall. Because, in case of this GCP set, we removed outlier using only RANSAC based on RFM. So, points of this GCP set were more fitted to sensor model compared with GCP set acquired from multi-patch and multi-band based matching. On the other hand, in case of check point accuracy, the GCP set acquired from multi-patch and multi-band based matching showed the better accuracy. As confirmed in the previous experiment, this is why the GCP accuracy was higher for this GCP set. Check point accuracy is a more reliable indicator because it shows the sensor model accuracy with points not used for modeling. Therefore, the proposed method showed better matching performance.

4. CONCLUSIONS

In this paper we proposed a method to improve sensor model accuracy using multi-patch and multi-band based matching. To obtain a sufficient number of high-quality GCP data using a limited number of GCP chips, we divided an original GCP Chip into 6 patches and 3 bands. For improve matching success rate of each patch, it is important to adjust search range precisely. There was a difference of about 10% matching success rate according to the adjustment of the precision search area. Compared with single-patch and single-band matching, the proposed method shows a higher number of GCPs, more accurate GCP accuracy, and checkpoint sensor model accuracy. We expect that the proposed method could be applied to automated geometric correction of CAS satellite series.

5. ACKNOWLEDGEMENT

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6. REFERENCES

Hwang, D., Lim, J. and Jun, H., 2016. Current Status and Future Prospects of Satellite Technology in Korea, 44(8), pp. 702-709.

Jeong, J., Kim, J. and Kim, T., 2014. Analysis of Geolocation Accuracy of KOMPSAT-3 Imagery. Korean Journal of Remote Sensing, 30(1), pp. 37-45.

Kang, M. and Y. Lim, 2015. A Study on the Application Demand of Satellite-based Information to Support National Land Polices, Korea Research Institute for Human Settlements, Anyang, Republic of Korea

Lee, K., Kim, Y. and Choi, H., 2017. KOMPSAT Image Processing and Applications. Korean Journal of Remote Sensing, 33(6), pp. 1171-1177.

Son, J., Yoon, W., Park, H., and Kim, T., 2019. A Method to Improve Rational Function Model Accuracy using Automated GCP Matching and RANSAC. In: Proceedings of the KOGSIS, Busan, Korea.

Yoon, W., Park, H. and Kim, T., 2018. Feasibility Analysis of Precise Sensor Modelling for KOMPSAT-3A Imagery Using Unified Control Points. Korean Journal of Remote Sensing, 34(6), pp. 1089-1100.

Yoon, W., and Kim, T., 2018. Bundle Adjustment of KOMPSAT-3A Strip Based on Rational Function Model. Korean Journal of Remote Sensing, 34(3), pp. 565-578.

Yoon,W., 2019. A Study on Development of Automatic GCP Matching Technology for CAS-500 Imager. Master's thesis. Inha university. 1-69.